A STUDY OF LAHAINA SILTY CLAY SOILS FORMING FROM DIFFERENT PARENT MATERIALS

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INTRODUCTION

Parent material is one of the five factors of soil formation. Sometimes it is the dominant factor as in soils developed from limestone or marls. When the effect of parent material is the dominating influence over the zonal effect of climate and vegetation, intrazonal soils are formed. As Baldwin et al. (1938) stated "The intrazonal soils have more or less well-developed soil characteristics that reflect the dominating influence of some local factor of relief or parent material over the normal effect of the climate and vegetation." Other times parent material is just one of the lesser factors which together with climate, organism, relief, and time give a soil its characteristic properties.

In recent years the realization of the importance of parent material has been greatly reasserted with the increased interest in Pleistocene chronology and the relation of soil to Pleistocene surface. A current view is that each surface, being of different age, gives rise to a different soil. Thorp (1965) summarized the current view well when he stated "Part of the voluminous and varied record of the Quaternary concerns soils that have been buried by sediments geologically assignable to various stages of this geological period; and part is in the form of soil profiles showing the different degrees and stages of horizon development that correspond to the different lengths of time during which the soil materials have been exposed to soil-forming processes. Positive relationships between soil-profile differences and land surfaces exposed for different lengths of time is good evidence that soils continue to change as long as they are exposed to weathering,

leaching, biological activity, and slow erosion, and that soil profiles probably never reach a state of complete equilibrium with their environments." This is possibly true in temperate regions of the earth and in tropical zones where it is relatively dry. In humid tropics, where the rates of chemical weathering and pedogenesis are presumably much greater than in temperate regions and dry tropical zones, soils appear to have little or no relation to Pleistocene surfaces. It is evident at least in Hawaii that surfaces younger than the Waipahu soil have a clear relation to Pleistocene surface but the Waipahu soil and older surfaces appear to have no relation to Pleistocene surface. The relative lack of importance of age of parent material beyond a certain youthfulness can be ascribed to a process called pedogenic convergence. When a surface is exposed to the atmosphere it will start to weather and a soil will start to form upon it. The earlier stages of both processes will be relatively rapid, but as the materials approach equilibrium with their environment, the rate of the processes will decrease and will eventually reach dynamic equilibrium. If time is sufficient and soil forming processes are intense enough, materials of different age or composition will converge to the same state of dynamic equilibrium. This is pedogenic convergence. The trend towards pedogenic convergence will occur in all climates but it seems probable that only in the humid tropics will practical pedogenic convergence be achieved.

The main objective of this thesis was to demonstrate pedogenic convergence in a series of important agricultural soils. It was found, however, that soils had not converged in all respects and certain trace elements remained divergent, so that it became possible to develop a discriminating function which separates parent rocks of Hawaiian soils.

REVIEW OF LITERATURE

Soil and Parent Material Relationships

Soil workers have long been interested in the effects of parent material on soil properties and in fact the earliest systems of soil classification were entirely geological. Cobb (1927) worked with soils developed from acidic and basic crystalline rocks of North Carolina. He found that young soils were quite different from each other in chemical composition, while old soils were more similar but still distinguishable. Hart (1935), worked with Scottish soils from different parent materials formed under identical conditions of climate and topography. He reported that basic rocks produced brown earths and acidic rocks produced podzols. Hosking (1940) stated that there was a relationship between the type of clay minerals formed and the parent material of the soils.

Modern pedologists are still interested in parent material effects, but there has been a change in thinking about what constitutes parent material. It is now recognized at least in the temperate areas, that young alluvium from basalt is a different parent material than old alluvium from basalt. Geomorphic surfaces of different age and nature will produce different soil parent materials although the original rock may be the same. Ruhe (1960), studied soils in Iowa and separated soil landscapes into four elements: upland, pediment backslope, pediment footslope, and alluvial toeslope. Each of the elements were considered to be different parent materials. The parent material differed due to the differential separation of the particles. He found that soil

characteristics of the four landscape elements differed due to the variation of parent material. Butler (1959), who worked in temperate Southern Australia, introduced the idea of periodicity in landscape events. He referred to this phenomenon as the K Cycle, and it is defined as "the interval of time covering the formation, (sic) by erosion and/or deposition of a new landscape surface, the period of development of the soils on that surface, and ending with the renewal of erosion of and/or deposition on that surface." Butler's study enables one to recognize chronological sequences of soil development.

One of Hawaii's most important soils is the Lahaina silty clay, gently sloping phase, occurring on the islands of Maui, Oahu, and Lanai. The soil is a Typic Haplustox, clayey, oxidic, hypermesic family. Over 14,000 acres of this soil are used intensively for pineapple and sugar cane cultivation. Since it is one of the most important agricultural soils in Hawaii, significant variation within the series or within the phases of the series will affect management of the soils. Cline et al. (1955), mapped the Lahaina silty clay soils formed from a variety of parent materials. This indicates that at the soil type subdivision of soil classification, competent soil morphologists have failed to observe differences among soils formed from different parent materials. Thus it would seem that the Lahaina soils, at least morphologically, have attained pedogenic convergence. Although the Lahaina soils forming from different parent materials have similar morphologies, the complete pedogenic convergence of the soils cannot be assumed. Neustruev (1927) has warned us not to assume too much. He said "parent materials are far from being a blank sheet of paper on which the climate may write anything it desires."

SOIL DESCRIPTIONS

Five profiles of Lahaina silty clay, gently sloping phase, were selected for this study. Two of the profiles were developed from andesite, and other three from basalt. Six or seven horizons were sampled from each profile. Details of sampling localities and parent rocks are given in Table I. The soils from West Maui were collected by Dr. L. D. Swindale and Dr. G. D. Sherman. From Molokai, two profiles were collected by Mr. S. Nakamura, Dr. Swindale and the author. The soil samples from Oahu were obtained from the Soil Conservation Service.

Lahaina, Maui from Mugearite (profile 1)

0-8" Dark reddish-brown (5 YR 3/3) silty clay; weak fine granular structure, friable, slightly sticky, plastic, abundant fine pores, clear smooth boundary.

8-11" Dark reddish-brown (5 YR 3/3) silty clay; weak fine granular structure, friable, slightly sticky, plastic, abundant fine pores, clear smooth boundary.

11-18" Dark reddish-brown (5 YR 3/4) silty clay; weak fine subangular blocky structure; friable, slightly compact in place, sticky, plastic, abundant pores, gradual smooth boundary.

18-24" Dark reddish-brown (5 YR 3/4) silty clay; strong fine to moderate subangular blocky structure, sticky, plastic, many pores.

24-36" Dark reddish-brown (5 YR 3/4) silty clay; strong fine to medium subangular blocky structure, sticky, plastic, many pores.

TABLE I. LOCATIONS OF LAHAINA SOIL PROFILES INVESTIGATED

Location	Parent Material
Lahaina, Maui Approximately 0.7 miles west of Honokahu below Pineapple Hill, near Honoapiilani Highway.	mugearite (alkalic andesite)
Hoolehua, Molokai Approximately 0.7 miles north-northeast of Hoolehua Post Office in C.P.C. Field B22, Block 3 (formerly 59).	andesite
Lahaina, Maui Approximately 0.6 miles southeast of Puukolii below a transverse drainage ditch.	olivine basalt
West Molokai Approximately 50 yards east of the main road, on the Mauna Loa northern end of Libby Field No. 16.	olivine basalt
Oahu Approximately 2000 feet north-northeast of a reservoir on the interfluve between Kipapa Gulch and Panakauahi Gulch.	olivine basalt

Hoolehua, Molokai from andesite (profile 2)

0-6" Dark reddish-brown (5 YR 3/4) silty clay; reddish-brown (5 YR 4/4) when dry; some clods and weak fine granular structure and weak fine and very fine subangular blocky structure; very hard, firm, very sticky and very plastic; common roots; many interstitial and very tiny tubular pores; common very fine black concretions; moderate effervescence with H_2O_2; common fine hard earthy lumps which are easily crushed by rubbing; slightly acid (pH 6.2); gradual wavy boundary 4 to 7 inches thick.

6-12" Dark reddish-brown (2.5 YR 3/3) silty clay; reddish-brown (5 YR 4/4) when dry; cloddy with weak medium and fine subangular blocky structure and some weak fine granular structure; very hard, friable, very sticky, very plastic; many roots; many very fine and few fine tubular pores; common very fine black concretions; moderate effervescence with H_2O_2; common fine hard earthy lumps which are easily crushed; medium acid (pH 6.0) 4 to 7 inches thick.

12-25" Dark reddish-brown (2.5 YR 3/4) silty clay; reddish-brown (2.5 YR 4/4) when dry; moderate medium subangular blocky structure breaking into moderate fine and very fine subangular and angular blocky structure; hard, friable, very sticky and very plastic; few roots; many very fine and fine tubular pores; few very fine black concretions; weak effervescence with H_2O_2; weak patchy glaze on ped faces; firm in place; neutral (pH 6.8); gradual wavy boundary; 10 to 15 inches thick.

25-44" Dark reddish-brown (2.5 YR 3/4 moist and dry) silty clay; moderate fine and very fine subangular blocky structure; hard, friable, sticky and plastic, no roots; many very fine and common fine tubular and dendritic pores; few very fine block concretion; weak effervescence with H_2O_2 except on concretions where effervescence is moderate; common patchy glaze on ped faces; firm in place; many hard earthy lumps which disappear after prolonged rubbing; neutral (pH 6.8); gradual wavy boundary.

44-58" Dark reddish-brown (2.5 YR 3/4 moist and dry) silty clay; moderate fine and very fine angular and subangular blocky structures; hard, slightly firm; sticky and very plastic; many very fine and fine tubular and dendritic pores; weak patchy glaze on ped faces; moderately firm in place; neutral (pH 6.8).

Lahaina, Maui from Olivine Basalt (profile 3)

0-15" Dark reddish-brown (2.5 YR 3/4) silty clay; weak fine granular structure, friable, slightly sticky, plastic, many fine pores, clear smooth boundary.

15-19" Dark reddish-brown (2.5 YR 3/4) silty clay; weak fine subangular blocky structure, friable, compact in place, sticky, plastic, many pores, gradual smooth boundary.

19-25" Dark reddish-brown (2.5 YR 3/4) silty clay, medium, fine, granular structure, friable, compact in place, sticky, plastic, many pores, gradual smooth boundary.

25-32" Dark reddish-brown (2.5 YR 3/4) silty clay, medium friable granular structure, friable, very compact in place, sticky, plastic, many pores.

West Molokai from Olivine Basalt (profile 4)

0-9" Dark reddish-brown (2.5 YR 3/4) silty clay; reddish-brown (5 YR 4/4) when dry; weak very fine granular structure, friable, sticky, plastic, many roots, many pores, clear wavy boundary 8 to 10 inches thick.

9-14" Yellowish-red (5 YR 4/6) silty clay; reddish-brown (2.5 YR 3/4) when dry; weak medium subangular blocky structure; friable, slightly sticky, plastic, few roots, many very fine pores, common very fine black concretions, black stains in pores; clear, wavy boundary 5 to 7 inches thick.

14-16" Yellowish-red (5 YR 4/8) silty clay; reddish-brown (2.5 YR 3/4) when dry; moderate very fine subangular blocky structure; friable, slightly sticky, plastic, few roots, many very fine tubular pores, many very fine black concretions; continuous thin stress cutans, black stains in some pores; clear to wavy boundary 10-to 13 inches thick.

26-48" Red (2.5 YR 4/6) clay; reddish-brown (2.5 YR 3/4) when dry; strong fine subangular blocky structure; friable, compact in place, slightly sticky, plastic, few roots, many very fine tubular pores, many very fine black concretions, continuous thin stress cutans, black stains in some pores, many hard earthy lumps, clear to wavy boundary 20 to 24 inches thick.

48-60" Dark reddish-brown (2.5 YR 4/6) silty clay; reddish brown (2 YR 3/4) when dry; moderate medium subangular blocky structure; friable, slightly sticky, plastic, no roots, few black stains in old root channels, almost continuous cutans, many very fine, common, medium tubular pores.

60" Auger sample.

Oahu, from Olivine Basalt (profile 5)

0-11" Weak-red (10 R 3.5/3) clay that feels like silty clay, dusky red (10 R 2.5/3) when moist; cloddy and weak very fine granular structure; friable, sticky and plastic; very few pores because of compaction by trucks and machinery; about 30 percent hydrogen peroxide; pH 5.7; clear smooth boundary.

11-21" Weak-red (10 R 3.5/4) clay that feels like silty clay, dusky red (10 R 3/4) when moist; weak very fine and fine subangular blocky structure; friable, sticky and plastic; many very fine and fine common medium pores; common thin patchy coatings; common iron-manganese concretions; moderate reaction with hydrogen peroxide; pH 6.6; clear wavy boundary.

21-31" Dusky-red (10 R 3/4) clay that feels like silty clay, dusky red (10 R 2.5/4) when moist; strong very fine and fine subangular blocky structure; friable, sticky and plastic; many very fine, common fine pores; continuous thin coatings; compact in place; few manganese stains; common iron-manganese concretions; slight reaction with peroxide; pH 6.8.

METHODS

Total Chemical Analysis

The procedure used by Dr. T. Katsura (1961) during his stay at the University of Hawaii was followed. Details are as follows:

Gravimetry

A 0.4 gram sample was ignited to obtain the loss on ignition (L.O.I.). The sample was then treated with Na_2CO_3 and silica was determined after dehydration in HCl solution. The R_2O_3 was determined by precipitating as the hydroxides in ammonia solution. After filtration, calcium was precipitated as calcium oxalate in the filtrate and determined by titrating with standard potassium permanganate. Magnesium was precipitated as magnesium phosphate.

Colorimetry

A 0.4 gram sample was ignited and treated with $HF-H_2SO_4$. The phosphorus, manganese, iron, and titanium were determined colorimetrically using ammonium molybdate-vandate, potassium periodate, a-a' bipirydyl, and hydrogen peroxide, respectively.

Subtraction

The alumina was determined by subtracting the phosphorus, iron and titanium from the R_2O_3 content.

Flame Photometry

A portion of the ignited, $HF-H_2SO_4$ treated sample was used to determine potassium and sodium. The potassium and sodium were determined by recording the intensity of flame at 768 and 589 mu, respectively.

Mineralogical

X-ray

The clay fraction of the soils was obtained by the method of Jackson (1956). The soils are first treated with sodium acetate, then hydrogen peroxide, and sodium dithionite to remove divalent cations, organic matter, and free iron oxide, respectively.

The clays to be investigated were saturated with potassium by washing it several times with N potassium chloride and then with alcohol-water mixture to remove the excess potassium chloride. Parallel, oriented samples were obtained by drying the clays on glass slides. The samples were first X-rayed using a Norelco X-ray diffractometer at room temperature, then again after heating for 3 hours at 350° C and 550° C, respectively. Another portion of the clays was saturated with magnesium by washing it several times with N magnesium chloride and then washing with water-alcohol mixture to remove the excess magnesium chloride. The clays were dispersed in water and transferred to a glass slide where it was allowed to dry in parallel orientation. The sample was then glycolated by placing the slide in an ethylene glycol environment for 48 hours. The glycolated sample was X-rayed at room temperature.

D.T.A.

A portion of 100-mesh soil was placed in a desiccator containing a saturated solution of $Mg(NO_3)_2$. The samples were left to equilibrate with the humidity created by the $Mg(NO_3)_2$ for approximately 20 days. The soil sample and the calcine alumina were heated at a rate of 150° C

increase per minute. To obtain quantitative kaolin and gibbsite, the method described by Matsusaka (1952) was followed since the same differential thermal apparatus was used.

Illite

Approximately 0.4 gram of the organic matter-free, deferrated, sodium saturated clay size fraction was treated with HF-H_2SO_4. The potassium content was determined by use of a Beckman flame photometer. The illite content in the clay fraction was determined by multiplying the K_2O content by 7.20. The 7.20 factor was obtained by Juang (1964). This convergence factor may be used since the mica is presumed to be similar in composition, due to its similar origin, and there are no other clay minerals in the clay fraction which have significant amounts of K_2O.

Extractable Trace Elements

Zinc

A 20 gram sample of oven-dried soil was placed in a 500 ml Erlenmeyer flask and 200 ml of 0.1N HCl was added. An aliquot of the filtered extract was taken and evaporated to dryness, digested with 10 ml HNO_3 and re-evaporated to dryness. The residue was dissolved with 2N HCl and filtered. The filtrate was analyzed for zinc by the Rush and Yoe method (1954).

Phosphorus

The available phosphorus was extracted with dilute 0.02N H_2SO_4 and determined colorimetrically as the phophomolybdenum blue complex. The method of Truog (1930) modified by Ayres and Hagihara (1952) was followed.

Total Trace Elements

Zirconium

Total zirconium was determined by X-ray fluorescence. For this method, a Norelco X-ray spectrometer was used with LiF analyzer crystal and tungsten tube operating at 50 K.V. and 50 M.A.

The sample in which zirconium was to be determined was first oven-dried and ground to 250 mesh size, mixed well, and loaded into a plastic slide. The sample was then inserted into the excitation chamber and scanned from 37 to 20 degrees 2 θ. The peak heights of the tungsten L-gamma, the strontium K-alpha and the zirconium K-alpha peaks were measured. A correction was made for the interference of the strontium K-beta peak with the zirconium K-alpha peak, by subtracting 16 percent of the strontium K-alpha peak from the zirconium K-alpha peak. Then the ratio I_{Zr} (intensity of zirconium K-alpha)/I_W (intensity of tungsten L-gamma) was obtained.

A calibration curve was obtained by measuring the I_{Zr}/I_W ratio for two soils to which increasing amounts of zirconium salts were added, and plotting I_{Zr}/I_W against total zirconium. The coefficient of variation for a single sample was 7 percent. (N. T. Hubbard assisted in the development of this method.)

Nickel

The Sandel-Pierlich colorimetric method for nickel modified by Chang and Sherman (1953) for Hawaiian soils was followed.

PEDOGENIC CONVERGENCE

The Lahaina soils are the result of weathering and pedogenesis of the parent rocks and parent materials, where the dominant soil forming process is laterization. The high and rather constant temperature (72° F) with a rainfall of 20 to 40 inches per year, has over a period of time resulted in the rapid and complete breakdown of primary minerals, with the exception of magnetite and ilmenite. The general processes involved are the release and removal of silica and the release and accumulation of sesquioxides. Due to the low rainfall, the Lahaina soil profile lacks translocation and accumulation of clays and results in uniform morphological characteristics of the profile. The morphological descriptions of the profiles sampled bear out this aspect of pedogenic convergence. It was mentioned earlier that although the Lahaina soils are formed from different parent rocks and different parent materials, they are classified into the same subdivision of soil classification, the phase. Thus, it would seem that the Lahaina soils forming from different parent materials, have attained pedogenic convergence.

Test of Pedogenic Convergence

Any measurable property of the five Lahaina profiles can be tested for pedogenic convergence by statistical methods. Since the number of individuals in the andesitic and basaltic soils differed, the Student's "t" test for unpaired group comparison, as described by Snedecor (1962), was followed.

The condensed formula used was:

$$t = (\bar{x}_1 - \bar{x}_2) \sqrt{\frac{n_1 \; n_2 \; (n_1 + n_2 - 2)}{(n_1 + n_2) \quad x^2}}$$

where,

$\bar{x}_1$ = mean of the basaltic constituent

$\bar{x}_2$ = mean of the andesitic constituent

n_1 = number of basaltic individuals

n_2 = number of andesitic individuals

x^2 = corrected sum of squares of the basaltic individuals + sum of squares of the andesitic individuals.

Chemical Properties

Properties studied

The major chemical constituents of the five Lahaina soil profiles were analyzed. The chemical constituents were SiO_2, Al_2O_3, Fe_2O_3, TiO_2, MgO, K_2O, Na_2O, and P_2O_5. The Fe_2O_3 content of the Lahaina soils are fairly high and relatively large amounts exist in the soil as free iron oxides in various forms such as amorphous oxide, hematite, magnatite, maghemite, goethite, and lepidocrocite. Since the method used cannot extract iron from magnetite and maghemites, the term free iron oxide used here is meant to be the extractable iron determined by the aforementioned method. Watanabe (personal communication) found that free iron oxide content of Hawaiian soils increased in passing from the Low Humic Latosol to Humic Ferruginous Latosol and then decreased progressively with the increasing rainfall.

Statistical test of chemical properties

The results of the total chemical analyses are given in Table II and III. The hawaiite from the alkalic suite contains appreciably more K_2O than the olivine basalt rocks and this difference may be inherited by the soil to some extent. But if this is true, then the mugearite-derived soil should contain the highest K_2O content since the mugearite rock has the highest amount of K_2O among the parent rocks of the Lahaina soils. Since the Lahaina soil derived from mugearite has similar K_2O content as the Lahaina soils derived from olivine basalt, it seems that the K_2O content of Lahaina soils does not depend on parent rock.

The high K_2O content of the soil developed from hawaiite could be attributed to its development from alluvium. Juang (1964) found that illite and its related K_2O content increased with increasing rainfall and elevation. Thus, the Humic Ferruginous and the Humic Latosols occurring physically above the Lahaina soil, should contain more illite than the Lahaina soils. It is shown in Fig 4 that the Lahaina soil derived from hawaiite is developed from alluvium. Thus, the high K_2O content of the hawaiite-derived soil appears to be due to its accumulation in the form of "pedogenic mica in the higher rainfall and elevation, and its deposition over the current vicinity where the present Lahaina soil is located.

The "t" values for the major chemical constituents are given in Table IV. The results show that the major chemical constituents of the five soil profiles are not significantly different at the 5 percent level except for the total K_2O content. The unpaired group comparison

TABLE II. TOTAL CHEMICAL ANALYSIS OF ANDESITIC LAHAINA SOILS

Island	Parent Material	Depth in Inches	L.O.I. %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	TiO_2 %	MgO %	CaO %	MnO %	K_2O %	Na_2O %	P_2O_5 %	Total
Maui	andesite	0 - 7	14.43	35.73	28.10	15.81	2.62	0.24	1.26	0.55	1.15	0.69	0.44	101.02
		11 - 16	13.73	35.84	30.01	15.50	2.52	0.20	1.17	0.46	1.06	0.72	0.28	101.52
		17 - 24	13.94	35.21	30.02	15.21	2.60	0.18	0.90	0.31	0.63	0.52	0.25	99.77
		26 - 36	13.69	35.13	30.69	15.19	2.52	0.25	0.96	0.29	0.31	0.44	0.27	99.64
		42 - 48	14.33	35.47	29.11	15.20	2.50	0.45	0.99	0.19	0.31	0.44	0.21	99.20
		48 - 60	14.13	36.26	29.21	14.87	2.38	0.57	0.76	0.21	0.51	0.44	0.18	99.52
Molokai	andesite	0 - 2	12.11	25.89	22.51	29.21	5.17	0.50	0.51	0.35	1.19	0.49	0.71	98.64
		5 - 11	12.48	26.06	22.48	28.33	5.12	0.32	0.41	0.30	1.19	0.50	0.72	98.27
		13 - 24	11.69	29.59	22.80	28.82	5.04	0.20	0.50	0.28	1.09	0.51	0.48	101.00
		25 - 44	11.80	28.81	20.08	30.69	5.22	0.32	0.70	0.20	1.11	0.52	0.57	100.02
		44 - 62	12.29	25.31	21.65	32.55	5.63	0.25	0.75	0.11	0.78	0.50	0.49	100.04
		64 - 76	11.73	26.54	20.85	33.92	5.41	0.47	1.05	0.04	0.69	0.53	0.52	101.75
		76 - 88	12.75	23.74	21.06	34.11	5.09	0.52	1.05	0.03	0.44	0.57	0.80	100.16
		Mean	12.93	30.00	25.27	23.80	3.99	0.34	0.85	0.26	0.80	0.53	0.46	

TABLE III. TOTAL CHEMICAL ANALYSIS OF BASALTIC LAHAINA SOILS

Island	Parent Material	Depth in Inches	L.O.I %	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	TiO_2 %	MgO %	CaO %	MnO %	K_2O %	Na_2O %	P_2O_5 %	Total
Maui	olivine basalt	3 - 12	13.15	29.60	25.02	24.18	3.92	0.49	1.30	0.50	0.44	0.50	0.44	99.54
		19 - 25	12.01	28.97	26.74	24.02	3.71	0.25	1.10	0.46	0.31	0.53	0.18	98.28
		26 - 30	12.08	29.94	27.83	22.81	3.70	0.30	1.27	0.45	0.31	0.53	0.25	99.47
		32 - 42	12.32	29.90	27.86	23.87	3.71	0.29	0.92	0.33	0.25	0.51	0.18	100.14
		42 - 51	11.94	30.32	27.96	23.99	3.82	0.24	0.77	0.16	0.13	0.53	0.20	100.10
		51 - 58	11.62	31.09	27.02	23.26	3.82	0.23	1.05	0.16	0.06	0.56	0.20	99.07
		58 - 64	11.21	33.01	26.83	23.26	3.72	0.91	1.33	0.26	0.06	0.54	0.49	101.62
Molokai	olivine basalt	0 - 9	11.21	30.64	26.01	25.42	3.57	0.43	0.83	0.36	0.75	0.42	0.30	99.94
		9 - 14	11.38	30.42	26.74	25.30	3.64	0.20	0.90	0.14	0.63	0.41	0.30	100.06
		16 - 26	12.15	28.45	26.64	25.53	3.74	0.22	0.48	0.14	0.50	0.44	0.28	98.57
		26 - 48	11.52	29.88	25.80	25.40	3.74	0.26	0.39	0.11	0.69	0.64	0.19	98.62
		48 - 60	12.03	29.37	25.92	24.30	4.03	0.30	0.51	0.06	0.88	0.43	0.29	98.12
		64 +	11.44	26.94	26.52	27.28	4.28	0.32	0.75	0.04	0.50	0.43	0.19	98.69
Oahu	olivine basalt	0 - 10	14.66	30.46	28.23	20.45	3.39	0.42	0.35	0.60	1.09	0.48	0.41	100.36
		10 - 16	14.49	30.47	29.02	18.91	3.44	0.45	0.37	0.62	1.00	0.47	0.41	99.65
		16 - 23	13.02	30.24	28.90	20.94	3.74	0.31	0.30	0.18	0.81	0.45	0.16	99.05
		23 - 32	12.60	28.96	30.32	21.70	3.54	0.33	0.21	0.15	0.63	0.48	0.16	99.08
		32 - 45	12.82	28.99	28.50	23.24	4.06	0.36	0.24	0.06	0.31	0.46	0.19	99.23
		45 - 65	13.51	30.67	28.08	23.07	4.55	0.30	0.27	0.05	0.06	0.50	0.38	101.44
		Mean	12.38	29.91	27.37	23.52	3.80	0.35	0.70	0.25	0.50	0.49	0.25	

TABLE IV. GROUP COMPARISONS FOR CHEMICAL AND MINERALOGICAL CHARACTERISTICS OF THE LAHAINA SOILS EXAMINED

Major Const.	"t" value+
SiO_2	0.72
Al_2O_3	1.99
Fe_2O_3	0.16
TiO_2	0.18
MgO	0.08
CaO	0.50
MnO	0.00
K_2O	2.52*
Na_2O	0.29
P_2O_5	0.40
Kaolin (whole soil)	0.80
Gibbsite (whole soil)	0.75
Illite (clay fraction)	3.15**
Free Fe_2O_3	0.87
Ext. Zn	0.18
Ext. P	1.27

+There were 30 degrees of freedom for each "t" test.

t = 2.02 at 5 percent level.

t = 2.75 at 1 percent level.

showed that there is no significant difference of free iron oxide between andesitic- and basaltic-derived soils (Table IV). This may be misleading because the free iron content of the Lahaina soil derived from mugearite is obviously lower than all the other Lahaina profiles. The insignificant "t" value is due to the high free iron content of the hawaiite-derived soil, which is probably derived from alluvium. Thus, the free iron oxide may not seem to converge when the parent materials are as different as mugearite and olivine basalt.

Mineralogical Properties

Semi-quantitative analysis of clay minerals

X-ray analysis showed that kaolin is the dominant clay mineral with varying amounts of gibbsite and illite. The lower horizons of the profiles tend to have broader kaolin peaks and upon glycolation, the kaolin peak expanded from 7.15 A to a broad 10 to 11 A peak (the X-ray results are filed in the Department of Agronomy and Soil Science, University of Hawaii). This indicates that halloysite tends to increase with depth. This is in agreement with work done by Saing (1964).

The kaolin and gibbsite contents were determined by use of differential thermal analysis (Table V). Pure samples of kaolin and gibbsite were used for standard curves. Four concentrations of kaolin and gibbsite were made by mixtures with calcined alumina. A plot of the peak area versus concentration resulted in a standard curve for semi-quantitatively estimating the kaolin and gibbsite contents. The illite content of the clay fraction was determined by multiplying the total K_2O by 7.20, a factor obtained by Juang (1964). The results are given in Table V.

TABLE V. MINERALOGICAL AND FREE IRON OXIDE ANALYSIS OF THE LAHAINA SOILS

Island	Parent Material	Depth in Inches	% Kaolin in Soil	% Gibbsite in Soil	% Illite in $<2\mu$	% Free Fe_2O_3
Maui	mugearite	0 - 7	60	1.0	7.3	11.60
		11 - 16	65	1.0	6.3	11.20
		17 - 24	70	1.0	5.0	10.02
		26 - 36	70	-	2.7	9.60
		42 - 48	70	-	2.0	8.80
		48 - 60	70	-	1.4	8.60
Molokai	andesite	0 - 2	35	3.0	13.0	16.00
		5 - 11	35	2.5	12.1	15.36
		13 - 24	35	3.0	11.7	16.40
		25 - 44	40	-	12.6	18.80
		44 - 62	40	2.0	11.2	21.18
		64 - 76	40	-	8.9	22.72
		76 - 88	40	1.0	3.6	22.56
Maui	olivine basalt	3 - 12	50	3.0	3.4	17.20
		19 - 25	45	3.0	3.2	17.04
		26 - 30	50	2.0	2.7	16.80
		32 - 42	45	2.0	1.0	16.06
		42 - 51	45	1.0	0.4	15.20
		51 - 58	45	-	0.4	10.40
		58 - 64	45	-	-	9.80
Molokai	olivine basalt	0 - 9	35	3.0	5.0	15.24
		9 - 14	35	1.0	5.0	15.30
		16 - 26	45	1.0	4.5	15.24
		26 - 48	55	1.0	5.4	16.96
		48 - 60	35	0.5	6.8	19.68
		60 +	35	2.0	4.0	19.20
Oahu	olivine basalt	0 - 10	50	3.0	8.1	15.10
		10 - 16	50	3.0	7.4	15.62
		16 - 23	55	1.0	6.0	15.05
		23 - 32	55	0.5	4.6	14.88
		32 - 45	60	-	3.2	15.84
		45 - 65	60	-	0.4	14.24

Statistical test of mineralogical properties

The unpaired group comparison "t" test for kaolin and gibbsite was not significant. The "t" values for kaolin and gibbsite are given in Table IV. The "t" value obtained for the illite content was significant at the 5 percent level (Table V). Since the illite content of the clay fraction and the total K_2O are related, the significant difference is probably explained by the high illite content of the soil derived from hawaiite which is believed to be derived from alluvium.

Extractable Nutrients

Properties studied

The growth of plants are influenced by many external factors such as light, mechanical support, heat, air, water, and nutrients. Research has shown that only 16 elements are universally required for normal plant growth, 2 of which are zinc and phosphorus. Zinc and phosphorus were selected for this study since their distribution in igneous rocks differ due to magmatic differentiation and correlation to plant yield data on Hawaiian soils are available.

Zinc

Rankama and Sahama (1949) mentioned that the average zinc content in igneous rocks is 132 ppm. Mitchell (1955) stated that basic rocks contained 100 to 200 ppm zinc and acidic rocks contained approximately 50 ppm zinc. Rader et al. (1964) found that the Hawaiian basalts and olivine basalts contained 89 to 120 ppm zinc. Although zinc data for andesitic Hawaiian rocks are unavailable, it is presumed that zinc behaves normally (decrease with increasing acidity) in magmatic differentiation of Hawaiian rocks.

The availability of zinc for plant growth depends on the total supply governed by the parent rock and its availability in the soil, affected by the soil matrix. Tucker and Kurtz (1955) concluded that zinc extracted with 0.1N HCl provided the best correlation with plant response. Kanehiro (1964), working with Hawaiian soils, found that the range of total zinc was between 50 to 288 ppm and extractable zinc was between 0.1 to 18 ppm. He found that the acidic latosols with less than 2 ppm zinc generally showed zinc deficiency and the addition of 18 lbs zinc/acre to these soils gave optimum response in yield using tomato, alfalfa, and corn as indicator plants. The results indicate that most of the acid tropical soils are deficient in zinc.

Phosphorus

The total phosphorus in the soil is not as important as the available phosphorus. The amount of available phosphorus in soils depends on many factors, such as pH, moisture, organic matter, temperature, mineralogy, and other ions. In strongly weathered tropical soils, the high amounts of hydrated aluminum and iron oxides affect phosphorus availability. DeDatta et al. (1963) found that 87.5 and 175 lbs/A phosphorus added to Molokai soil increased the yield of sudan grass. Gamido (1964) working with 24 Hawaiian soils, found that the mean yield for panicum grass increased 45 percent with addition of 200 ppm phosphorus. He found that the Lahaina soils responded tremendously to phosphorus applications.

Humbert and Ayres (1952) found that the critical level of phosphorus for sugar cane soils was approximately 20 ppm. They also found that the amounts and distribution of phosphorus in soil profiles varies

considerably even at the family level and that the available phosphorus is exceedingly low in some of the acid oxide soils of Hawaii.

Statistical test of extractable nutrients

The results of extractable zinc and phosphorus are given in Table VI. The Student's "t" test for unpaired group comparisons (Table IV) show that there is no significant difference in extractable zinc between Lahaina soils formed from andesite and olivine basalt. The "t" test for phosphorus show no significant difference between the andesite and basaltic Lahaina soils.

Distribution and availability

The results show that there is a general decrease of both zinc and phosphorus with depth (Table VI). The results also show that, with the exception of most surface horizons, the Lahaina soils are deficient in zinc and phosphorus according to the criteria mentioned by Kanehiro (1964) and Humbert and Ayres (1952), respectively. The high zinc and phosphorus content of surface horizons is probably due to fertilization or recycling by organic matter.

Trace Elements

Elements studied

Oven-dried portions of the Lahaina soils were analyzed by the X-ray fluorescence technique. Since the Lahaina soils forming from different parent materials have rather similar matrices, qualitative differences of trace elements between andesitic- and basaltic-derived Lahaina soils were obtained. Some of the trace elements, such as zinc

TABLE VI. EXTRACTABLE PHOSPHORUS AND ZINC, TOTAL ZIRCONIUM AND NICKEL, AND DISCRIMINANT FUNCTION RESULTS OF THE LAHAINA SOILS

Island	Parent Material	Depth in Inches	Extr. ppm P	Extr. ppm Zn	Total ppm Zr	Total ppm Ni	D.F.
Maui	andesite	0 - 7	15	3.0	931	74	825
		11 - 16	5	0.9	909	69	810
		17 - 24	5	1.1	1050	69	951
		26 - 36	3	0.9	1097	57	1015
		42 - 48	4	0.7	1097	49	1027
		48 - 60	4	0.6	1097	46	1031
Molokai	andesite	0 - 2	24	2.9	564	182	303
		5 - 11	23	1.1	600	175	349
		13 - 24	14	0.9	559	180	301
		25 - 44	12	0.8	559	185	293
		44 - 62	14	0.8	545	188	275
		64 - 76	43	0.5	502	200	214
		76 - 88	43	1.8	507	190	234
Maui	olivine basalt	3 - 12	70	6.0	278	371	255
		19 - 25	8	0.8	264	354	244
		26 - 30	9	1.1	288	365	236
		32 - 42	8	0.6	276	357	237
		42 - 51	7	1.3	243	263	135
		51 - 58	8	0.5	271	257	98
		58 - 64	12	0.8	309	217	3
Molokai	olivine basalt	0 - 9	5	2.6	257	331	220
		9 - 14	2	0.7	300	320	161
		16 - 26	2	1.2	238	308	206
		26 - 48	2	0.5	238	317	218
		48 - 60	2	0.8	238	311	210
		60 +	3	0.7	245	309	200
Oahu	olivine basalt	0 - 10	27	5.8	278	565	533
		10 - 16	23	6.3	284	542	574
		16 - 23	8	5.1	238	514	500
		23 - 32	3	1.6	257	480	432
		32 - 45	2	1.4	300	485	396
		45 - 65	2	0.8	350	428	265

and molybdenum, appeared to have attained pedogenic convergence, whereas others did not, particularly zirconium and nickel.

Zirconium is high in the andesitic and trachytic rocks. It increases as the silica content increases. Nickel, which occupies lattice positions in olivine, is high in olivine-rich rocks, mainly basalts and olivine basalts, and it decreases in content as the silica content increases. There is a trend of increasing zirconium and decreasing nickel in passing from the more basic to the more acidic rocks. Since the X-ray fluorescence analysis qualitatively shows the divergence of zirconium and nickel and these two elements show opposing trends in magmatic differentiation, zirconium and nickel were selected for quantitative tests for pedogenic convergence.

Importance of zirconium and nickel in soils

Zirconium is considered important in studies of the origin and development of soils. Marshall and Haseman (1942) used zirconium as the primary indicator of gains and losses of materials in Grundy silt loam profile. Butler (1954) was able to distinguish between Carboniferous and Triassic Drift mixtures by use of zirconium content. The stability of zircon is useful in the study of soils in temperate regions. The stability of zircon in tropical areas in in question since Carroll (1953) has indicated that under strong conditions of weathering, zircon shows sign of being attacked. The Lahaina soils are strongly-weathered tropical soils. Under this condition, the test for the convergence of probably the most resistant element in soils, zirconium, will be attempted.

Nickel has not been established as an essential element for plant growth but its importance lies more on its toxic effect. Robinson et al. (1935) reported that high chromium and nickel may have been the cause of infertility of soils derived from serpentine. It is now accepted that excessive amounts of nickel in the soil will produce toxic effects on plant growth. Soils derived from basic to ultra-basic rocks will tend to have high nickel content, since nickel, having similar ionic radii as magnesium, tend to substitute for magnesium in olivines. Soils derived from acidic rocks will tend to have lower nickel content due to the decrease in olivine content. Thus, the Lahaina soils, being formed from andesitic and basaltic parent materials, may have different levels of nickel toxicity. Chang and Sherman (1953) observed toxic effects on tomato plants grown in pots filled with Kaniohe soil (4 percent quartz sand) with 400 ppm total nickel, on Koko Head soil with 884 ppm total nickel, and on Waimanalo soil with 779 ppm total nickel.

Statistical test of trace elements

The results of total soil zirconium and nickel are given in Table VI. The results show that for both zirconium and nickel, there is a complete separation between Lahaina soils derived from andesite and basalt for every horizon in every soil analyzed. A "t" test is unnecessary since it is obvious that both zirconium and nickel do not converge. Because of the lack of pedogenic convergence, the two elements may be used to discriminate between different parent rocks in strongly weathered tropical soils. The derivation of a discriminant function for this purpose is discussed in the next section.

THE IDENTIFICATION OF PARENT ROCKS

In soils, formed in humid tropical climates, the B and C horizons may extend 10's of feet beneath the surface without containing identifiable rock fragments. Therefore, it is exceedingly difficult to determine the nature of the parent rock. And yet it is often important to know the parent rock, for the soils, although similar, are not the same, and the differences may be important to soil management. Some soils in a series may, for example, show excesses of certain trace elements; others may not. If the excesses are related to parent rock, it becomes possible to predict their occurrence when the parent rock is known. Again, parent material is a factor of soil genesis, and the nature of parent material is determined by the nature of the parent rock. So, to describe soil genesis accurately, the parent rock must be known.

Nature of Hawaiian Rocks

Macdonald and Katsura (1964), divided the volcanic rocks of the Hawaiian Islands into two major suites: the tholeiitic suite, which constitutes approximately 95 percent of the total bulk and the alkalic suite, which forms a veneer over the main tholeiitic portion. The tholeiitic suite consists mainly of basalts, but also contains olivine basalts and oceanites. The alkalic suite, on the other hand, consists of a full range of rock types including ankaramite, olivine basalt, basalt, hawaiite, mugearite, and soda trachyte. Because of its superior position, the alkalic suite has much more importance in soil formation than its relative volume would suggest.

The trace element composition of Hawaiian rocks has been studied by Wager and Mitchell (1953) and Nockolds and Allen (1954, 1956). Zirconium, which may occur in rare zircon and as a lattice substituent in pyroxenes, feldspars, and apatites, is high in andesitic and trachytic rocks. It increases in content as the silica content increases. Nickel, which occupies lattice positions in olivines, is high in olivine-rich basalts and oceanites. It decreases in content as the silica content increases. In both suites of rocks, there is a general trend of increasing zirconium and decreasing nickel in passing from the more basic to the more acidic rocks. The range in values for either zirconium or nickel is larger in the alkalic than the tholeiitic suite.

Many of the chemical elements in rocks are removed during the processes of weathering and soil formation, while other elements tend to accumulate in the soils being formed. Tiller (1958) and Wells (1960) have shown that both zirconium and nickel tend to accumulate. Hence, because these two elements show opposing trends in magmatic differentiation, and because they both persist in strongly weathered soils, it seemed possible that a discriminant function based on the differences between total soil zirconium and total soil nickel might provide a useful and effective means of determining the parent rocks from which the soils were derived.

Development of the Discriminant Function

The discriminant function for Lahaina soils

Although the Lahaina soils were developed from different parent rocks, they are very similar morphologically, as is implied by the

morphological descriptions of the soils sampled. They are also similar in their main chemical and mineralogical properties, as is implied in the section on pedogenic convergence. Also, in that section, the total zirconium and nickel did not show pedogenic convergence. Kendall (1951) explains the basic theory of the discriminant function well. The procedure used to calculate the discriminant function was as follows:

$$D.F. = b_1 X_{Zr} + b_2 X_{Ni}$$

where,

X_{Zr} = total zirconium in the soil

X_{Ni} = total nickel in the soil

by solving b_1 and b_2 the coefficients obtained from the matrix equation:

$$S_{Zr}\, b_1 + S_{ZrNi}\, b_2 = d_1$$

$$S_{ZrNi}\, b_1 + S_{Ni}\, b_2 = d_2$$

where,

d_1 = mean difference of zirconium = $\bar{X}_{Zr}$ (andesite) - $\bar{X}_{Zr}$ (basalt)

d_2 = mean difference of zirconium = $\bar{X}_{Ni}$ (andesite) - $\bar{X}_{Ni}$ (andesite)

S_{Zr} = pooled variance for zirconium =

$$\frac{\leqq X^2_{Zr}\ (\text{andesite}) - X^2_{Zr}\ (\text{basalt})}{n\ (\text{andesite}) - 1 + n\ (\text{basalt}) - 1}$$

S_{Ni} = pooled variance for nickel =

$$\frac{\leqq X^2_{Ni}\ (\text{andesite}) - \leqq X^2_{Ni}\ (\text{basalt})}{n\ (\text{andesite}) - 1 + n\ (\text{basalt}) - 1}$$

S_{ZrNi} = pooled covariance of zirconium and nickel =

$$\frac{\leqq X_{ZrNi}\ (\text{andesite}) - \leqq X_{ZrNi}\ (\text{basalt})}{n\ (\text{andesite}) - 1 + n\ (\text{basalt}) - 1}$$

The amounts of total zirconium and total nickel were determined for the five profiles (Table V). From these figures a discriminant

function was calculated to separate andesite-derived and basalt-derived soils. The matrix equations were:

$$27{,}221.2b_1 - 6{,}825.9b_2 = 503.6$$

$$-6{,}825.9b_1 - 7{,}812.1b_2 = -245.4$$

which gave $b_1 = 0.0136$, $b_2 = 0.0195$, equivalent to the discriminant function

$$D.F. = Zr - 1.44\ Ni$$

To test the significance of the function obtained, an "F" test was carried out using the formula:

$$F_{P/N-P-1} = \frac{N_1 N_2\ (N-P-1)}{PN\ (N-2)} \cdot D^2$$

Where,

N_1 = number of zirconium or nickel observations for andesites

N_2 = number of zirconium or nickel observations for basalts

P = variables fitted (2)

$D^2 = b_1 d_1 + b_2 d_2$

The F value obtained was 15.77, indicating a highly significant separation between the two groups of soils. The quality of this separation is shown in Fig 1 in which the function Zr - 1.44 Ni is plotted against total Zr for the five soils.

The discriminant function for Hawaiian rocks

The discriminant function developed for the Lahaina soils was applied to the analyses of Hawaiian andesites and basalts given in the literature and to some data kindly supplied by N. J. Hubbard (1965). The results are shown in Fig 2 in which the discriminant function

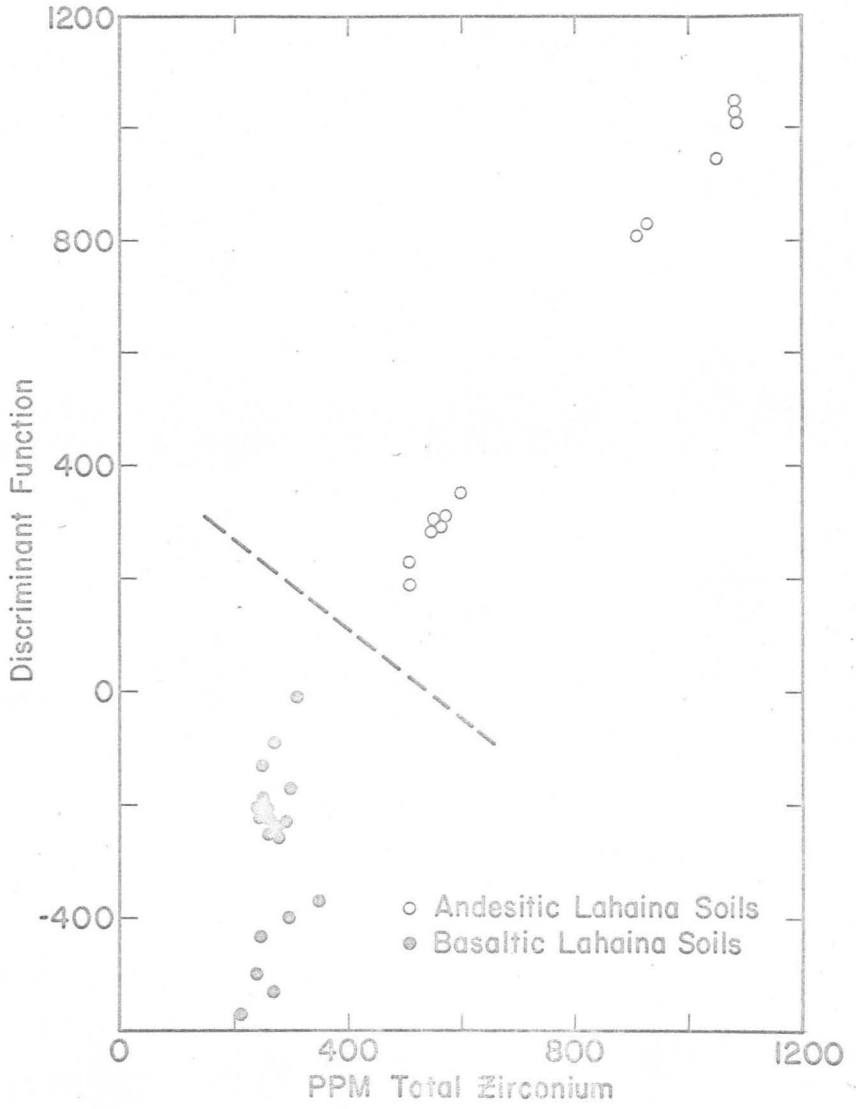

FIG 1. DISCRIMINANT FUNCTION FOR LAHAINA SOILS PLOTTED AGAINST TOTAL ZIRCONIUM

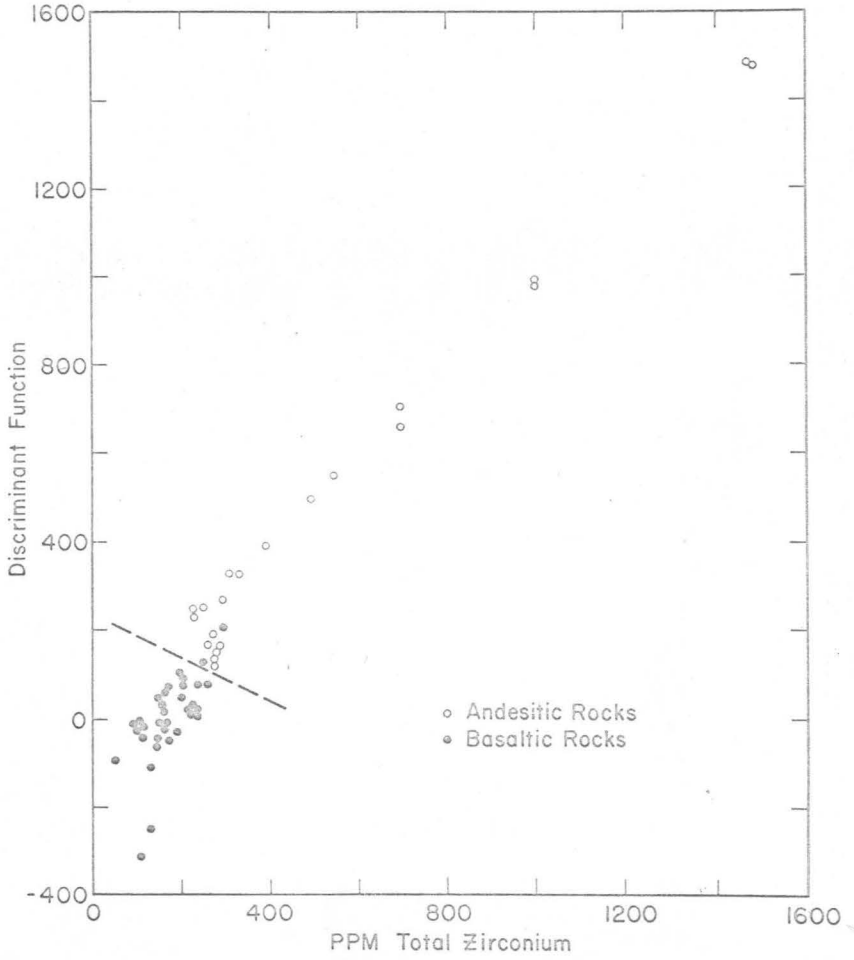

FIG 2. DISCRIMINANT FUNCTION FOR UNWEATHERED ROCKS PLOTTED AGAINST TOTAL ZIRCONIUM

Zr - 1.44 Ni is plotted against total Zr. As is to be expected in rocks formed by magmatic differentiation the results fall fairly uniformly along a straight line, but the dashed line in the figure separates rocks that are recognized petrographically as andesites from those that are recognized as basalts with only a small amount of overlap.

The discriminant function for other soils

A discriminant function developed for Lahaina soils, which also discriminates well between andesitic and basaltic parent rocks, can be expected to discriminate between andesite-derived and basalt-derived soils which are as more or less weathered or pedogenetically developed than the Lahaina series. In Hawaii this would include all other Typic Haploxerox and all Tropusterts from residual parent materials.

To determine the extent to which the discriminant function could be applied to soils more weathered or developed than the Lahaina series, two additional sequences of soils were sampled and analyzed (Mr. Floyd Stevens aided in collection of the samples). Both sequences were taken on West Maui; one on the same interfluve as, and topographically above, the Lahaina soil from andesite, and the other on the same interfluve as, and physically above, the Lahaina soil from basalt. The sequence on andesite included a Kahana soil (Alfic Haplustox), a Honolua (Orthoxic Tropohumult), a soil related to the Paaloa series (Humoxic Tropohumult) and a soil related to the Olokui series (Typic Tropaquod). The sequence on basalt was confined to two soils because andesites and andesitic ash cap the higher slopes of all the West Maui mountains. They were a Kahana soil (Alfic Haplustox) and a Halawa soil

(Orthoxic Tropohumult). Some important genetic data for these soils are given in Table VII. The zirconium and nickel data and the calculated discriminant functions are given in Table VIII. The discriminant function Zr - Ni for these soils is plotted against total zirconium in Fig 3. The soils derived from the two rock types are clearly separated by the discriminant function. Serveral other interesting relationships among the results obtained are discussed in the following section.

Discussion

Little or no previous work has been done in determining the mode of occurrence of zirconium in Hawaiian rocks or soils. It is known in general that zirconium in soils occurs in zircon or dispersed as the oxide within secondary iron oxides. However, zircon is unreported in Hawaiian rocks, but may occur in mugearite. In the soils studied, the primary minerals, with the exception of the iron oxides, have been weathered away. Hence zirconium probably occurs in the soils as the dioxide, either discrete or dispersed within the secondary oxides.

The nickel in the rocks is associated with iron and magnesium and occurs mainly in olivines with lesser amounts in pyroxenes, iron oxides, and a trace amount in the feldspars. Of these minerals, only the iron oxides occur in the soils, and the nickel probably exists in mixed oxides of several valencies either discrete or in association with secondary oxides.

The effect of weathering and pedo development on the amount and distribution of zirconium and nickel in Hawaiian soils can be ascertained from consideration of Tables VII and VIII. As the rainfall

TABLE VII. GENETIC DATA FOR WEST MAUI SOILS

Soil	Parent Material	Elevation	% Slope	Approximate Rainfall	Vegetation
Lahaina	mugearite	80'	5	35"	pineapple
Kahana	mugearite	650'	-	45"	pineapple
Honolua	mugearite	1000'	12	60"	guava, Christmas berry, false staghorn fern
Paaloa	mugearite	1600'	15	80"	false staghorn fern, club moss, guava, foxtail
Olokui	mugearite	2800'	-	100"	treefern, ohia, Cheirodendron spp., sedges, Pelea
Lahaina	olivine basalt	530'	12	35"	sugar cane
Kahana	olivine basalt	1300'	-	45"	foxtail, guava, lantana, klu
Halawa	olivine basalt	2000'	-	60"	treefern, foxtail, false staghorn fern, koa, ohia

TABLE VIII. TOTAL ZIRCONIUM AND NICKEL IN SOILS DESCRIBED IN TABLE VII

Soil	Parent Material	Horizon	ppm Zr	ppm Ni	Discr. Function
Lahaina	andesite	A_p	931	74	824
		A_{p2}	909	69	810
		B_1	1050	59	965
		B_2	1097	57	1015
		B_3	1097	49	1026
		C_1	1097	46	1031
Kahana	andesite	A	802	63	711
		B	1133	75	1025
		C	1493	70	1392
Honolua	andesite	A	1296	75	1188
		B	1483	88	1356
		C	2122	100	1978
Paaloa	andesite	A	1087	45	1022
		B	1414	52	1339
		C	2525	60	2439
Olokui	andesite	A	1051	25	1015
		B	2472	42	2412
		C	2064	30	2021
Lahaina	olivine basalt	A_{p1}	278	371	-256
		A_{p2}	264	354	-246
		B_1	288	365	-238
		B_2	276	357	-238
		B_3	243	263	-136
		C_1	271	257	- 99
		C_2	309	217	- 3
Kahana	olivine basalt	A	271	255	- 96
		B	319	360	-199
		C	312	331	-165
Halawa	olivine basalt	A_{12}	383	132	+193
		B_{21}	374	345	-123
		B_{22}	281	360	-237
		B_3	286	365	-240
		C	334	371	-200

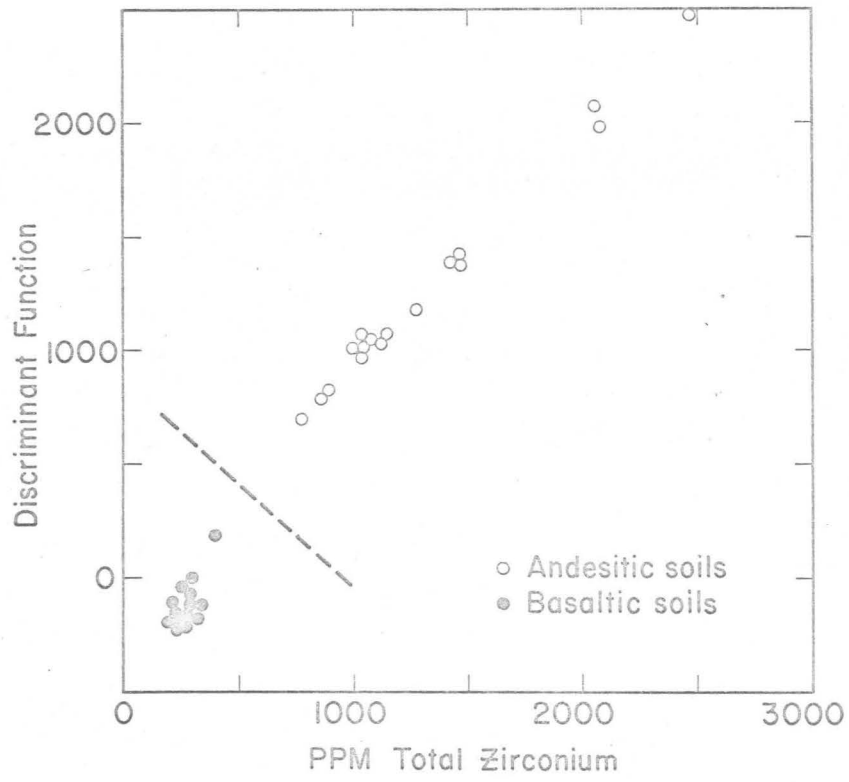

FIG 3. DISCRIMINANT FUNCTION FOR ANDESITIC AND BASALTIC SOILS PLOTTED AGAINST TOTAL ZIRCONIUM

and degrees of weathering increases, the total zirconium in the solum increases. Total nickel in the solum increases up to a rainfall of about 50 inches, the upper limit of the Haploxerox, and then decreases progressively. It is probable that reducing conditions in the Tropohumults and Tropaquod are the cause of this depletion in nickel.

Zirconium is distributed uniformly throughout the Lahaina profile but is leached, probably by cheluviation, from the upper horizons of more developed soils. In the Olokui-like soil zirconium is deposited in the thin, indurated, iron-rich, spodic horizon. The eluviation of zirconium from the upper horizons of this soil resembles that found by Swindale and Jackson (1956) for the Parahaki soil, a podzolized yellow-brown earth formed from rhyolite under kauri forest vegetation in New Zealand. Nickel is concentrated in the upper horizon, but is leached from the topsoil of the more developed soils. In the Tropohumults and the Tropaquod some nickel is leached out of the profile, but the extent of the leaching is greatest in the epipedon. There is apparently a relative accumulation of nickel in the spodic horizon of the Tropaquod.

Although nickel has a greater tendency than zirconium to be removed from the soils in the sequences, the behavior of the two elements is sufficiently similar for the discriminant function to separate clearly between andesite-derived and basalt-derived materials from each horizon for every soil analyzed. The discriminant function of the Halawa soil shows that some contamination probably by andesitic ash has occurred in the topmost horizon. There is ample morphological evidence to support this, and it has in fact been suggested that Halawa soils be classified as Oxic Normandepts because of the common occurrence of ash in them.

DISCRIMINATING SOILS FROM RESIDUUM AND ALLUVIUM

Introduction

Soils from residuum are soils which are developing in place, from the original parent rock, whereas soils from alluvium are soils developing from previously weathered material that has been moved by the action of water and re-deposited. Soils from residuum and alluvium will tend to attain pedogenic convergence in respect to pedogenetic development. The degree of pedogenic convergence depends on the nature of parent material, climate, vegetation, topography, and time. In humid tropics, pedogenic convergence is most likely to occur, depending mainly on the age of the alluvium. One of the factors causing age differences among alluvium is sea level changes. Ruhe (1965), working with Oahu soils, stated "After sea-level lowering and emergence of the marine sediments, a new parent material became available for soil formation." Soils from old alluvium is difficult to distinguish from soils from residuum due to its high degree of pedogenetic development under humid tropical conditions.

Importance

The identification of soils formed from residuum and soils from alluvium is important in order to better understand their origin, development and properties. Specific reasons for the importance of identification are as follows:

1. Soils from residuum may differ from soils from alluvium in some aspects of physical properties, particularly impermeability.

2. Soils from residuum may differ from soils from alluvium in certain aspects of soil fertility that will influence soil management.
3. Identification will be utilized in interpretation of certain soil genesis problems.
4. A better understanding of tropical soil cycling may be attained.

Behavior of Pedogenetic Mica and Discriminant Function

Juang (1964) found that the mica in Hawaiian soils is pedogenetic in origin and that its content decreased with depth in all of the soils worked with. The soils are believed to be derived from residuum. It has also been found that the distribution of mica content with depth is constant in some of the soil profiles analyzed by the Department of Agronomy and Soil Science, University of Hawaii, for the Soil Conservation Service. The profiles in which the distribution of mica content with depth is constant are believed to be derived from alluvium. Consequently, the mica trend can possibly be used as a criterion for differentiating between soils derived from residuum and soils derived from alluvium.

A discriminant function for Lahaina soils was obtained in the previous section. The discriminant function which is presumably affected by pedogenetic processes, shows two types of trends down the soil profile: increasing and constant. It is presumed that the increasing trend is due to the formation of the soil from residuum, whereas the constant trend indicates its development from alluvium. Thus, the behavior of the discriminant function down a profile, like the mica

content, should differentiate between soils from residuum or alluvium and a combination of both should indicate the difference better than either parameter alone. A plot of the discriminant function against percent mica content in the clay fraction is shown in Fig 4.

Results and Discussion

The results show two distinct patterns: one a linear arrangement of points, and the other, an irregular distribution. The Maui and Oahu soil profiles show a linear pattern and are probably formed from residuum. The two soil profiles from Molokai show an irregular pattern and are believed to have been derived from alluvium. The Lahaina soil from Molokai which formed from andesite appears to have developed from residuum and alluvium. The last two horizons indicate that they are from residuum.

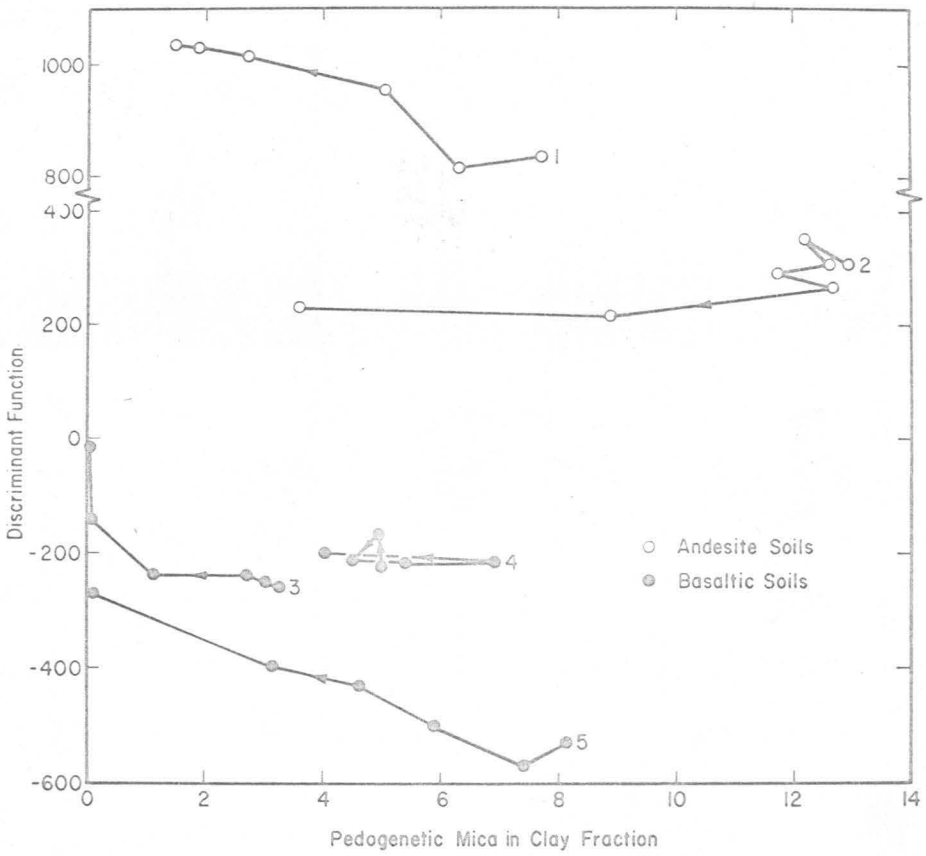

FIG 4. DISCRIMINANT FUNCTION FOR LAHAINA SOILS PLOTTED AGAINST PEDOGENETIC MICA:
1 = MUGEARITIC PROFILE FROM LAHAINA, MAUI;
2 = ANDESITIC PROFILE FROM HOOLEHUA, MOLOKAI;
3,4,5 = BASALTIC PROFILES FROM LAHAINA, MAUI, WEST MOLOKAI, AND OAHU, RESPECTIVELY

SUMMARY

Statistical test of the chemical and mineralogical properties indicate that the Lahaina silty clay soils have attained pedogenic convergence with the exception of the K_2O and the related pedogenic mica content. The divergence of K_2O and mica is probably dependent on the parent material instead of the parent rock. The extractable zinc and phosphorus appear to have converged and are deficient in the subsoils of Lahaina soils. The high zinc and phosphorus contents of surface horizons is probably due to fertilization or recycling by organic matter. The total zirconium and nickel of the Lahaina soils did not attain pedogenic convergence. Due to the divergence of zirconium and nickel, a discriminant function was developed to separate the rocks of these highly weathered soils.

A discriminant function of the form Zr - 1.44 Ni has been developed to distinguish between parent rocks of strongly weathered Hawaiian soils. The function was primarily developed for use with Lahaina silty clay soils but was extended successfully for use with unweathered rocks and with a wide range of Hawaiian soils. It was found that total zirconium in the solum increased with increasing weathering: total nickel in the solum increased up to the upper limit of the Haploxerox and then decreased progressively. With increasing pedogenetic development, zirconium tended to be eluviated from the upper horizons, and accumulation of zirconium was found in the spodic horizon of a Tropaquod. With increasing pedogenetic development, nickel tended to be eluviated from the profile, with the greatest

eluviation in the upper horizons. A relative accumulation of nickel occurred in the spodic horizon of the Tropaquod. Although zirconium and nickel have different distribution patterns throughout the soils, the discriminant function successfully differentiated andesite-derived from basalt-derived materials for every horizon in every soil analyzed.

The behavior of the discriminant function and pedogenetic mica differentiated Lahaina soils from residuum and alluvium. The discriminant function for the soils plotted against mica content of the clay fraction show two distinct patterns: one a linear and the other an irregular. The Maui and Oahu soil profiles which show a linear pattern of points are probably formed from residuum, whereas the two Molokai soil profiles which show an irregular pattern are believed to be formed from alluvium. The andesitic Lahaina soil from Molokai appears to have developed from residuum and alluvium.

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